

# **SYSTEM AND METHOD FOR ADDING LOCAL RESOURCES FOR USE BY A MOBILE AGENT OBJECT**

## **CROSS REFERENCE TO RELATED APPLICATION**

[1] This application claims the benefit of co-pending Provisional Patent Application Serial No. 60/398,888 filed July 26, 2002 entitled "Adding Local Resources for use by Mobile Agents."

## **TECHNICAL FIELD OF THE INVENTION**

[2] The present invention relates, generally, to a distributed computing environment wherein processes created in an object-oriented environment direct their own movement throughout a computer network, and, in particular, relates to the adding of local resources within host-computing environments for use by mobile agents running therein.

## **BACKGROUND OF THE INVENTION**

[3] The advent of computer networks has proliferated the use of distributed-computing environments. A distributed-computing environment is a type of computing wherein several computer platforms, *i.e.*, different computers, coupled by a network, perform separate but related tasks, (called a process), that are directed in concert

toward a single achievement. One example of such a process is the retrieval of all files in a network having the same pattern of letters in the file name. By taking advantage of the computing power of several computers at once, tasks require less time for completion. Use of a processor close to resources to be processed reduces total computing resource requirements.

**[4]** One method known in the art for practicing a distributed-computing environment is called "remote programming." In remote programming, a first executing program, called a client process, executing on a first computer system, sends to a second process, called a server process executing on the second computer system, a list of instructions. The instructions are then carried out on the second computer system by the server process, effectuating the goal of the client process. The instructions that the server process is designed to carry out must have some degree of generality, *i.e.*, the instructions must allow some degree of local decision-making with respect to details.

**[5]** U.S. Patent No. 6,016,393 to White et al., entitled, "System and Method for Distributed Computation Based upon the Movement, Execution, and Interaction of Processes in a Network", which is hereby incorporated by reference, disclosed a system that improved upon the concept of remote programming by utilizing processes called mobile agents (sometimes referred to as mobile objects or agent objects). The system described by White et al., provides the ability for an object (the mobile agent object), existing on a first ("host") computer system, to transplant itself to a second ("remote host") computer system while preserving its current execution state. The operation of a mobile agent object is described briefly below.

[6] The instructions of the mobile agent object, its preserved execution state, and other objects owned by the mobile agent object are packaged, or "encoded", to generate a string of data that is configured so that the string of data can be transported by all standard means of communication over a computer network. Once transported to the remote host, the string of data is decoded to generate a computer process, still called the mobile agent object, within the remote host system. The decoded mobile agent object includes those objects encoded as described above and remains in its preserved execution state. The remote host computer system resumes execution of the mobile agent object which is now operating in the remote host environment.

[7] While now operating in the new environment, the instructions of the mobile agent object are executed by the remote host to perform operations of any complexity, including defining, creating, and manipulating data objects and interacting with other remote host computer objects. These interactions may be handled through processes called services. A typical mobile agent object may discover and use services and log the calls to and usage of such services. A system and method directed to the discovery and monitoring of services is disclosed in co-pending U.S. Patent Application

\_\_\_\_\_, entitled "SYSTEM AND METHOD FOR THE DISCOVERY OF AND USAGE OF LOCAL RESOURCES BY A MOBILE AGENT OBJECT," filed on July 11, 2003, which is assigned to Topia Ventures LLC and which is incorporated by reference.

[8] When a mobile agent object is operating in a remote host environment, specific services may be needed but not available within the area of execution of the mobile-agent object called the mobile-agent runtime environment. In such a case, the mobile

agent object may be programmed to skip over attempting to use the particular service. In other cases, the mobile agent object may not be programmed with the capacity to determine whether the service is available, thus causing delays and possibly even irretrievable loops. Still other mobile agent objects may be programmed to request the delivery of the service from the original host system for use in the new mobile agent runtime environment.

**[9]** If the service is requested from the original host system, the purpose of the mobile agent object is defeated in that the mobile agent object is intended to be implanted in a remote host computing environment to eliminate unnecessary communications over the network when data and information are required from the host computing environment. Since the mobile agent object needs to request a service object to be delivered from its original host computing environment to be used in the new mobile-agent runtime environment in the host computer system, communication over the network still occurs and there is no time and computing efficiency realized over the situation where the original host requests the needed data and information directly without using the mobile agent object.

**[10]** Therefore, a method and system for adding needed services by taking advantage of the mobile agent mechanism wherein communication over the network is minimized is desirable.

### **SUMMARY OF THE INVENTION**

**[11]** According to an embodiment of the invention, a system and method is presented for a mobile agent runtime environment to dynamically extend its capabilities. More specifically, the capabilities of a particular mobile-agent runtime environment are extended by the delivery, via a mobile agent object, of needed service modules that originate from a remote source. In one embodiment of the invention, a method includes the steps of executing a mobile agent object, (called a delivery-mobile agent object) in a mobile-agent runtime environment in a host computing environment and then installing a service object to be executable in the mobile-agent runtime environment.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[12]** The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

**[13]** **FIG. 1** is a block diagram of one embodiment of a distributed-computing environment suitable for practicing embodiments of the invention;

**[14]** **FIG. 2** is a block diagram of a host platform memory having a mobile-agent runtime environment residing therein according to an embodiment of the invention;

[15] **FIG. 3** is a block diagram delivery of a mobile agent object according to an embodiment of the invention; and

[16] **FIG. 4** is a flow diagram of a method for delivering services from a remote computing environment to a host computing environment through use of a delivery mobile agent object according to an embodiment of the invention.

#### **DETAILED DESCRIPTION**

[17] **FIG. 1** is a block diagram of a distributed-computing environment suitable for practicing embodiments of the invention. The distributed-computing environment includes a first computer system **100** (original host) and a second computer system **150** (remote host) that are coupled by a network connection, such as the internet **125** as shown in **FIG. 1**. The network connection may be any other connection, such as a Local Area Network (LAN) for example, that is suitable for facilitating communication between computer systems. Here, the first **100** and second **150** computer systems may communicate over the internet **125** using a standard protocol, such as, for example, Transmission Control Protocol/Internet Protocol (TCP/IP). Additionally, there are typically many more computer systems (not shown) coupled with the internet **125**, all of which may communicate with other computers on the network including the first and second computers **100** and **150**.

[18] The original host **100** includes a CPU **103** coupled to a bus **101** that facilitates communication between the CPU **103** and other components of the original host **100**.

Other components of the original host **100** include a Network Interface Component **102** (NIC) and a memory **104**. The memory may include magnetic or optical disks, Random-Access memory (RAM), Read-Only memory (ROM), Basic Input/Output Systems (BIOS), or any other commonly known memory system used in computer architecture. In the original host **100**, a mobile-agent runtime environment **110** and a mobile-agent injector program **111** are resident within the memory **104**. Although shown as separate memory components, the mobile-agent runtime environment **110** and a mobile-agent injector program **111** may reside in a single memory component or in any combination of memory components that are coupled with the bus **101**. The NIC **102** facilitates communications between the original host **100** and other computers, such as the remote host **150**, via the internet **125**.

[19] The remote host **150** is similar to the original host **100** and includes a CPU **153**, a bus **151**, a NIC **152**, and a host platform memory **154** which includes a mobile-agent runtime environment **160**. These components are organized and coupled as described above with respect to the original host **100**.

[20] The above-described distributed-computing environment may host one or more mobile agent objects (not shown) that are present in one of the mobile-agent runtime environments **110** or **160** of one of the computers **100** or **150**. The mobile-agent runtime environment **110** and **160** is a portion of the memory dedicated to allowing a mobile agent object the ability to perform operations that it was programmed to carry out. The nature of the mobile agent object, the manner in which the mobile agent object is transported between computers, and the parameters of the mobile agent object's

abilities are discussed in detail in White et al. (which has been incorporated by reference) and will not be discussed further herein.

**[21]** Mobile agent objects may be instantiated in a mobile-agent runtime environment **110** or **160** in several ways, two of which are briefly described here. In a first way, the mobile agent object is locally created in the original host **100** and then locally injected into the mobile-agent runtime environment **110** by the mobile-agent injector program **111**. In a second way, the mobile agent object moves from the mobile-agent runtime environment **110** of the original host **100** to the mobile-agent runtime environment **160** of the remote host **150** over the internet **125** by its own accord, *i.e.*, according to its programmed instructions. Both of these instantiation processes are well known in the prior art.

**[22]** **FIG. 2** is a block diagram of a host platform memory **154** having a mobile-agent runtime environment **160** residing therein according to an embodiment of the invention. In the host platform memory **154**, a method and system may be provided that enables a mobile agent runtime environment **160** with the ability to dynamically extend its capabilities. Specifically, capabilities are extended by the delivery, via a specific mobile agent object called a delivery mobile agent object **200**, of service modules **220** from a remote source, *i.e.*, the original host **110**.

**[23]** When a delivery mobile agent object **200** is instantiated in a new environment, such as the mobile-agent runtime environment **160** of the host platform memory, the delivery mobile agent object may be programmed to discover the services that are available in the mobile-agent runtime environment **160** in order to determine what



service objects **220** are available. The discovery of service objects is described in co-pending U.S. Patent Application \_\_\_\_\_, entitled "SYSTEM AND METHOD FOR THE DISCOVERY OF AND USAGE OF LOCAL RESOURCES BY A MOBILE AGENT OBJECT," mentioned above. By discovering services that are available, the delivery-mobile-agent object may determine what service objects do not exist in the mobile-agent runtime environment **160**. As such, the delivery mobile agent object **200** may then install the needed service objects **220** in the mobile-agent runtime environment **160**.

[24] In an alternative embodiment, the delivery mobile agent object **200** is programmed to install one or more specific service objects **220** without having to discover the current service objects **220** in the mobile-agent runtime environment **160**. This may be the case because a different mobile agent object (not shown) previously discovered the service objects **220** that are available and then relaying this information for the programming of the delivery-mobile-agent-object **200**.

[25] Still referring to **FIG. 2**, the mobile-agent runtime environment **160** is provided within the host platform memory **154** wherein a delivery-mobile-agent-object **200** may execute its instructions. As described above, the host platform memory **154** resides within a host computing environment on the remote host **150** accessible via the network (Internet **125** of **FIG. 1**) by the sender of the delivery-mobile-agent-object **200**, *i.e.*, the original host **100**. The mobile-agent runtime environment **160** also includes a number of service objects **220** that export an application programming interface (API) which are not shown in **FIG. 2**. Each API provides a communication channel to the CPU **153** of the

remote host **150** that enables each service object **220** the computing capabilities for performing its particular operations. Each service object **220** is also associated, through a binding relationship **230**, with a one or more related service modules **215** that realize the functionality of one or more service objects **220**. Each service object **220** may have more than one binding relationship **230** with a plurality of service modules **215**, and each service module **215** may have more than one binding relationship **230** with several service objects **220**. Service objects **220** and service modules **215** act in conjunction to carry out operations when its service is requested by any process or object, such as delivery mobile agent object **200**.

[26] For example, a particular service object **220** may be called by any number of processes or objects, such as the delivery-mobile-agent-object **200**. When called, the service object **220** initiates a CPU **153** request on its dedicated API. The CPU **153** handles all API traffic according to a known timing protocol. As such, when the CPU **153** decides that this particular API of the service object **220** is to be granted permission for execution, the CPU **153** carries out the instructions associated with the service object **220** which may be, for example, to list all service objects **220** available within the mobile-agent runtime environment **160**.

[27] One particular type of service object **220** is called a service delivery service object **210**. A service-delivery service object **210** is a realization of a service object **220** which defines an API that allows the delivery- mobile-agent-object **200** the ability to install, remove, and verify both service objects **220** and service modules **215**. Furthermore, the service-delivery service object **210** exports one or more APIs that allow

the delivery-mobile-agent-object **200** the ability to create binding relationships **230** between a particular kind of service module **215**, called a service-delivery service module **205**, and the service-delivery service object **210**. The service-delivery service module **205** is a realization of a service module **215** that implements the functionality of the service-delivery service object **210**. The operation and interaction between the above-described objects and components is described in greater detail below with respect to **FIG. 4**.

**[28]** **FIG. 3** is an exploded view of a block diagram of a delivery-mobile-agent-object **200** according to an embodiment of the invention. The delivery-mobile-agent-object **200** includes programmable instructions directed to the functions associated with the delivery-mobile-agent-object **200**. Specifically, the delivery-mobile-agent-object **200** includes a native-service module **301**, service-object byte code **302**, installation instructions **303**, and service-module runtime data **304**. These components facilitate the functions of a delivery-mobile-agent-object **200**.

**[29]** The native-service module **301** is a realization of a service module **215** that is incorporated within the delivery-mobile-agent-object **200** and that implements an API (not shown) as defined by the related service-object byte code **302** contained within the delivery-mobile-agent-object **200**. The native-service module **301** contains code that executes in the host platform memory (**154** in **FIG.1**) and may be compressed while resident in the delivery-mobile-agent-object **200**. When a delivery-mobile-agent-object **200** is first instantiated in a mobile-agent runtime environment **160**, the native-service module **301** is executed in the host platform memory **154** and, as such,

becomes “native” to the mobile-agent runtime environment **160** that is within the host platform memory **154**.

[30] The service-object byte code **302** is a realization of a service object **220** that is incorporated within the delivery-mobile-agent-object **200** and that defines an API whose implementation is intended to extend the functionality of the mobile-agent runtime environment **160** where the delivery-mobile-agent-object **200** is currently executing. The service-object byte code **302** is operable to create binding relationships (not shown) between service objects **220** and service modules **215** that are stored in the native-service module **301**.

[31] The installation instructions **303** are a set of instructions integral to the delivery-mobile-agent-object **200** which direct the service delivery service object **210** to carry out the installation of its service objects **220** and service modules **215**.

[32] The service- module runtime data **304** is used by the native-service module **301** during runtime. The data contained in the service- module runtime data **304** is dependent upon the intent and implementation of the native-service module **301**. That is, the service-module runtime data is directly related to the service objects **220** that are stored for installation in the native-service module **301**. The installation method is described further below with respect to **FIG. 4**.

[33] **FIG. 4** is a flow diagram of a method for delivering services from a host computing environment **100** to a remote host computing environment **150** through use of one or more delivery-mobile-agent-objects **200** according to an embodiment of the invention. At step **401**, a delivery-mobile-agent-object **200** is instantiated (discussed

previously) in a mobile-agent runtime environment **160** that is resident within a host platform memory **154**. The delivery-mobile-agent-object **200** already includes a number of service objects **220** and service modules **215** that are to be installed. The service objects **220** and service modules **215** are stored within the service-object byte code **302** and the native-service module **301**, respectively, prior to installation.

[34] Next, the delivery-mobile agent object **200** obtains the service-delivery service object **210** at step **403**. The delivery-mobile-agent-object **200**, already resident in the mobile-agent runtime environment **160**, obtains the service-delivery service object **210** in order to gain the use of an API to utilize the CPU **153** of the host system **150**.

[35] Next, at step **405**, the delivery-mobile-agent-object uses the API of the service-delivery service object **210** to install its native-service module **301**, its service-object byte code **302**, and its service-module runtime data **304** into the mobile-agent runtime environment **154** according to the computer-executable instructions included in the installation instructions **303**.

[36] Next, at step **407**, the delivery-mobile agent object **200** uses the API of the service-delivery service object **210** to create binding relationships **230** to map the installed native service module **301** to the associated service object byte code **302**. That is, the newly installed service objects **220** that came from the service-object byte code **302** and the newly installed service modules **215** that came from the native-service module **301** are mapped with various binding relationships according to the installation instructions. Finally, at step **409**, the delivery-mobile agent object **200** may be ejected from the mobile-agent runtime environment **154**, thus, completing the installation

method. Now, the newly installed service object may be called by any process or object that is executing in the mobile-agent runtime environment.

**[37]** The preceding discussion is presented to enable a person skilled in the art to make and use the invention. The general principles described herein may be applied to embodiments and applications other than those detailed above without departing from the spirit and scope of the present invention. The present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed or suggested herein.